PATENT COOPERATION TREATY

Ref/ARF

From the
INTERNATIONAL PRELIMINARY EXAMINING AUTHORITY

To:

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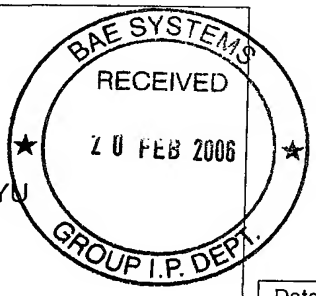


PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(PCT Rule 71.1)

Date of mailing *(day/month/year)*	16.02.2006
Applicant's or agent's file reference	**IMPORTANT NOTIFICATION**
XA1808	

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/GB2005/000652	22.02.2005	27.02.2004

Applicant
BAE SYSTEMS PLC et al.

1. The applicant is hereby notified that this International Preliminary Examining Authority transmits herewith the international preliminary report on patentability and its annexes, if any, established on the international application.

2. A copy of the report and its annexes, if any, is being transmitted to the International Bureau for communication to all the elected Offices.

3. Where required by any of the elected Offices, the International Bureau will prepare an English translation of the report (but not of any annexes) and will transmit such translation to those Offices.

4. **REMINDER**

The applicant must enter the national phase before each elected Office by performing certain acts (filing translations and paying national fees) within 30 months from the priority date (or later in some Offices) (Article 39(1)) (see also the reminder sent by the International Bureau with Form PCT/IB/301).

Where a translation of the international application must be furnished to an elected Office, that translation must contain a translation of any annexes to the international preliminary report on patentability. It is the applicant's responsibility to prepare and furnish such translation directly to each elected Office concerned.

For further details on the applicable time limits and requirements of the elected Offices, see Volume II of the PCT Applicant's Guide.

The applicant's attention is drawn to Article 33(5), which provides that the criteria of novelty, inventive step and industrial applicability described in Article 33(2) to (4) merely serve the purposes of international preliminary examination and that "any Contracting State may apply additional or different criteria for the purposes of deciding whether, in that State, the claimed inventions is patentable or not" (see also Article 27(5)). Such additional criteria may relate, for example, to exemptions from patentability, requirements for enabling disclosure, clarity and support for the claims.

Name and mailing address of the international preliminary examining authority:	Authorized Officer
European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Choulouilidou, C Tel. +49 89 2399-2257

Form PCT/IPEA/416 (January 2004)

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference XA1808	**FOR FURTHER ACTION**	See Form PCT/IPEA/416
International application No. PCT/GB2005/000652	International filing date *(day/month/year)* 22.02.2005	Priority date *(day/month/year)* 27.02.2004
International Patent Classification (IPC) or national classification and IPC G01P15/125, G01P1/00, G01P15/08		
Applicant BAE SYSTEMS PLC et al.		

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 5 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. ☒ *sent to the applicant and to the International Bureau)* a total of 15 sheets, as follows:
      ☒ sheets of the description, claims and/or drawings which have been amended and are the basis of this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      ☐ sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.
   b. ☐ *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or tables related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).

4. This report contains indications relating to the following items:

☒	Box No. I	Basis of the opinion
☐	Box No. II	Priority
☐	Box No. III	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
☐	Box No. IV	Lack of unity of invention
☒	Box No. V	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
☐	Box No. VI	Certain documents cited
☐	Box No. VII	Certain defects in the international application
☐	Box No. VIII	Certain observations on the international application

Date of submission of the demand	Date of completion of this report
21.12.2005	16.02.2006
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized Officer Trique, M Telephone No. +49 89 2399-6252

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

   ☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:
   - ☐ international search (under Rules 12.3 and 23.1(b))
   - ☐ publication of the international application (under Rule 12.4)
   - ☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements*** of the international application, this report is based on *(replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report)*:

Description, Pages

1-3, 5-16	as originally filed
4, 4a, 17, 18	received on 24.12.2005 with letter of 20.12.2005

Claims, Numbers

1-18	received on 24.12.2005 with letter of 20.12.2005

Drawings, Sheets

2/9, 6/9, 8/9	as originally filed
1/9, 3/9-5/9, 7/9, 9/9	received on 24.12.2005 with letter of 20.12.2005

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing

3. ☐ The amendments have resulted in the cancellation of:
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).
   - ☐ the description, pages
   - ☐ the claims, Nos.
   - ☐ the drawings, sheets/figs
   - ☐ the sequence listing *(specify)*:
   - ☐ any table(s) related to sequence listing *(specify)*:

* *If item 4 applies, some or all of these sheets may be marked "superseded."*

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-18
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-18
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-18
	No:	Claims	

2. Citations and explanations (Rule 70.7):

see separate sheet

RE ITEM V
REASONED STATEMENT UNDER ARTICLE 35(2) WITH REGARD TO NOVELTY AND INVENTIVE STEP

1. ***TECHNICAL FIELD***

The invention disclosed in claims 1 to 18 relates to an accelerometer with a comb-like structure.

2. ***CLOSEST STATE OF THE ART***

WO-A-98/52051 discloses an accelerometer having an inner frame for supporting the proof mass, said inner support frame being flexibly attached via coupling webs on two beams secured to the base at anchor points. The coupling webs which are arranged on each side of the inner support frame extend perpendicularly to the sensing direction.

3. ***NOVELTY - ART. 33 (2) PCT***

The subject-matter of the independent apparatus claim 1 differs from **WO'051** in particular in that:

- the inner support frame is suspended within a ring-like outer support frame by mounts arranged in the sensing direction; and
- the mounting legs connecting the proof mass to the inner support frame extend perpendicularly to the sensing direction.

Consequently, the subject-matter of claim 1 is novel.

4. ***INVENTIVE STEP - ART. 33 (3) PCT***

The claimed arrangement avoids compressive or tensile longitudinal forces due to a differential expansion rate between the support frame and the base to be transmitted to the mounting legs. The temperature dependence of the scale factor of the claimed accelerometer is thereby reduced and so its accuracy is improved.

This solution is not known from the prior art. In particular:

- **US'067**: accelerometer with an outer frame for supporting the proof mass.
- **US'589:** accelerometer with a protecting glass cap.
- **US'548:** differential accelerometer with a comb-like structure.
- **US'508:** accelerometer with shielding fingers.

Consequently, an inventive step of claim 1 is acknowledged.

5. *DEPENDENT CLAIMS*

The dependent claims 2 to 18 disclose preferred embodiments of the invention described in the independent claim 1. Consequently, their subject-matter also involves an inventive step (Art. 33(3) PCT).

WO 98/52051 teaches an accelerometer having a plate-like base made from an electrically non-conductive material, an outer support frame attached to the base, an inner substantially planar, ring-like, support frame flexibly suspended within the outer frame so that the inner frame is spaced from the base and co-planar with the outer support frame, a substantially planar plate-like proof mass, moveably mounted in the inner support frame which is co-planar therewith, and four or more flexible mounting legs each co-planar with the proof mass and inner support frame.

There is thus a need for a generally improved accelerometer which at least minimises the foregoing disadvantages inherent in the proposed accelerometer.

According to a first aspect of the present invention there is provided an accelerometer characterised in that

the outer support frame is substantially planar and ring like, the outer support frame being fixedly bonded to the base,

the inner support frame is flexibly suspended within the outer frame by mounts arranged in the sensing direction connecting the inner frame to the outer frame,

with each mounting leg being connected at one end to the proof mass and connected at another end to the inner support frame so that the proof mass is mounted for linear movement in a sensing direction in the plane containing the outer support frame, inner support frame, proof mass and mounting legs, in response to acceleration change applied to the accelerometer,

with the mounting legs extending substantially perpendicularly to the sensing direction,

and with the flexible suspension of the inner support frame reducing compressive and/or tensile forces on the mounting legs as a function of temperature on the accelerometer.

Preferably the outer support frame is anodically bonded to the base.

Conveniently the base material is glass.

forcing signal. Also during operation the control signal remains effectively the same regardless of the mark/space ratio, giving a more robust operation.

Normally the output of the mark to space ratio generator is from 0V to 5V so an analogue switch (such as a MAXIM part number MAX303) can be switched by this signal to increase the drive voltage to the 25V required for the typical silicon accelerometer to achieve a g range of 50g.

Thus with the accelerometer of the present invention it is possible to achieve a linear output with applied acceleration which can cover a milli-g range of between plus and minus 50 g with a noise floor of less than 40 micro-g per root Hz depending on the details of the output data rate. The use of the analogue output, using the drive voltages V_1 and V_2 as the output helps to ensure the overall accuracy of the accelerometer. Use of timing information of the mark/space ratio is prone to error in earlier proposed accelerometers due to variation in rise/fall times for their high voltage drives to the two terminals T_1 and T_3. The analogue output as used in the accelerometer of the present invention employing the low pass filtered version of the drive voltage, overcomes these problems.

Figures 17 and 18 of the accompanying drawings show a detail modification to the accelerometer of the present invention according to Figures 3 to 15. As previously pointed out the mounting of a silicon wafer directly onto a glass base 2 has potential disadvantages in that the differential expansion of the two materials implies that the silicon wafer will suffer flexure with temperature which in turn may give rise to accelerometer errors. Other possible disadvantages include ingress of dust, moisture and other gaseous impurities which may impede operation of the fingers 9 and give rise to an uncertain bias and scale factor, stiction and capacitance changes.

Accordingly, in the modification of Figures 17 and 18, a plate-like cap 36 is provided made from an electrically non-conductive material such as glass, anodically bonded to the silicon outer support frame 17 to form both a mechanical protection and a hermetic seal. Where the underlying silicon is moveable such as the proof mass 3, mounting legs 4 and fingers 9, the cap

may be pre-etched so as to be separate from these items so that they are free to move.

Wire bond pads 37 are provided on the silicon, such as on the outer support frame 17 and are exposed for wires to be attached thereto by apertures 38 there around provided through the cap 36, which apertures allow the cap 36 to maintain the hermetic seal around them. The outer support frame 17 which is anodically bonded to the glass base 2 is also anodically bonded to the cap 36. This allows hermetic sealing of the silicon wafer. Wire bonds 39 are thus attached to the bond pads 37 by intermediate ball bonds 40 conveniently made from gold.

The cap 36 thus balances the stresses that may occur between a silicon/glass structure by providing a glass/silicon/glass structure which will not be subject to bending. By appropriately choosing the anodically bonding temperature it is possible to vary the tension in the silicon wafer if required. As it is known that stress is locked into a structure at the bonding temperature a choice of the temperature and bonding conditions will allow a particular strain to be locked in if required.

The presence of the cap 36, which is a hermetic seal, allows the gaseous medium within the accelerometer to be chosen and set at manufacture independent of any handling after manufacture. Typically atmospheric pressure dry nitrogen may be used to perform the requisite damping. Other gases such as neon may be used which has the benefit of a higher viscosity than nitrogen. This increases the damping that is known to stabilise the closed loop operation of the accelerometer. A higher pressure of gas can slightly increase the viscosity.

CLAIMS

1. An accelerometer having

a plate-like base (2) made from an electrically non-conductive material,

an outer support frame (17) attached to the base (2),

an inner substantially planar, ring-like, support frame (18) flexibly suspended within the outer frame (17) so that the inner frame (18) is spaced from the base (2) and co-planar with the outer support frame (17),

a substantially planar plate-like proof mass (3) moveably mounted in the inner support frame (18) which is co-planar therewith, and

four or more flexible mounting legs (4) each co-planar with the proof mass (3) and inner support frame (18),

characterised in that the outer support frame (17) is substantially planar and ring like, the outer support frame (17) being fixedly bonded to the base (2)

the inner support frame (18) is flexibly suspended within the outer frame (17) by mounts (19) arranged in the sensing direction connecting the inner frame (18) to the outer frame (17),

with each mounting leg (4) being connected at one end to the proof mass (3) and connected at another end to the inner support frame (18) so that the proof mass (3) is mounted for linear movement in a sensing direction in the plane containing the outer support frame (17), inner support frame (18), proof mass (3) and mounting legs (4), in response to acceleration change applied to the accelerometer,

with the mounting legs (4) extending substantially perpendicularly to the sensing direction,

and with the flexible suspension of the inner support frame (18) reducing compressive and/or tensile forces on the mounting legs (4) as a function of temperature on the accelerometer.

2. An accelerometer according to Claim 1, wherein the outer support frame (17) is anodically bonded to the base (2).

3. An accelerometer according to Claim 2, wherein the base (2) material is glass.

4. An accelerometer according to Claim 3, including a plate-like cap (36), made from an electrically non-conductive material, anodically bonded to the outer support frame (17).

5. An accelerometer according to Claim 4, wherein the cap (36) material is glass.

6. An accelerometer according to Claim 5, including a plurality of interdigitated capacitor fingers fixedly mounted, in a gaseous medium, in the inner support frame (18) for sensing linear movement of, and for providing gaseous medium squeeze damping for, the proof mass (3) in the sensing direction, with the fingers, proof mass (3), mounting legs (4), inner support frame (18) and outer support frame (17) being co-planar and formed from a single plate of mono crystalline silicon.

7. An accelerometer according to Claim 6, wherein the gaseous medium is air, nitrogen or neon

8. An accelerometer according to Claim 7, wherein the fingers comprise fixed first (5), second (6), third (7) and fourth (8) arrays of laterally spaced fingers extending substantially perpendicularly to the sensing direction and away from the inner support frame (18) towards the proof mass (3), with the first (5) and second (6) arrays being located on one side of the proof mass (3) and with the third (7) and fourth (8) arrays being located on the opposite side of the proof mass (3), and moveable fifth (10), sixth (11), seventh (12) and eighth (13) arrays of laterally spaced finger extending substantially perpendicularly to the sensing direction from and attached to the proof mass (3) towards the inner

support frame (18), with the fifth (10) and sixth (11) arrays being located on said one side of the proof mass (3) and interdigitated respectively with the first (5) and second (6) arrays and with the seventh (12) and eighth (13) arrays being located on said opposite side of the proof mass (3) and interdigitated respectively with the third (7) and fourth (8) arrays, with the interdigitation of the first (5) and fifth (10) arrays and of the third (7) and seventh (12) arrays being at a first offset in one direction in the sensing direction from a median line between adjacent fingers in the first (5), second (6), third (7) and fourth (8) arrays, and with the interdigitation of the second (6) and sixth (11) arrays and of the fourth (8) and eighth (13) arrays being at a second offset equal and in the opposite direction to the first offset.

9. An accelerometer according to Claim 8, including means for providing a first drive voltage to the first (5) and third (7) offset arrays of fingers and a complementary opposite second drive voltage to the second (6) and fourth (8) offset arrays of fingers such that the interdigitated fingers provide for the proof mass (3) sensing of displacement in response to acceleration applied to the accelerometer, drive and damping of displacement, and means for providing pulse width modulation of the first and second drive voltages with a constant frequency to provide an electrostatic restoring force on the proof mass (3) according to

$$F = \frac{CV^2}{2d}$$

where F is the restoring force, C is the capacitance, V is the voltage between the first (5) and second (6) offset arrays of fingers and d is the capacitance gap between the fingers.

10. An accelerometer according to Claim 9, wherein the proof mass (3), mounting legs (4), inner (18) and outer (17) support frames and interdigitated fingers are formed by dry etching from a plate of silicon which is orientated in the [111] or [100] crystal plane.

11. An accelerometer according to Claim 10, wherein the outer support frame (17) has a substantially rectangular ring-like shape surrounding a

first inner open area in which is mounted the inner support frame (18) via two said mounts (19) spaced apart in the sensing direction and each connecting one side of the outer support frame (17) to one side of the inner support frame (18).

12. An accelerometer according to Claim 11, wherein the inner support frame (18) has a substantially rectangular ring-like shape surrounding a second inner open area in which is located the proof mass (3) which has a substantially rectangular shape, and wherein the mounting legs (4) extend substantially perpendicularly to the sensing direction in spaced array, with at least two legs (4) extending between a first inner wall of the inner support frame (18) defining the second inner open area and a facing first outer wall of the proof mass (3) and with at least two legs (4) extending between an opposing second inner wall of the inner support frame (18) defining the second inner open area and a facing second outer wall of the proof mass (3).

13. An accelerometer according to Claim 12, wherein the mounting legs (4) have high compliance in the sensing direction and low compliance in other directions.

14. An accelerometer according to Claim 13, wherein the outer support frame (17), first (5), second (6), third (7) and fourth (8) arrays of fingers are anodically bonded to the base (2) and wherein the mounting legs (4), proof mass (3), inner support frame (18) and fifth (10), sixth (11), seventh (12) and eighth (13) arrays of fingers are spaced from the base (2).

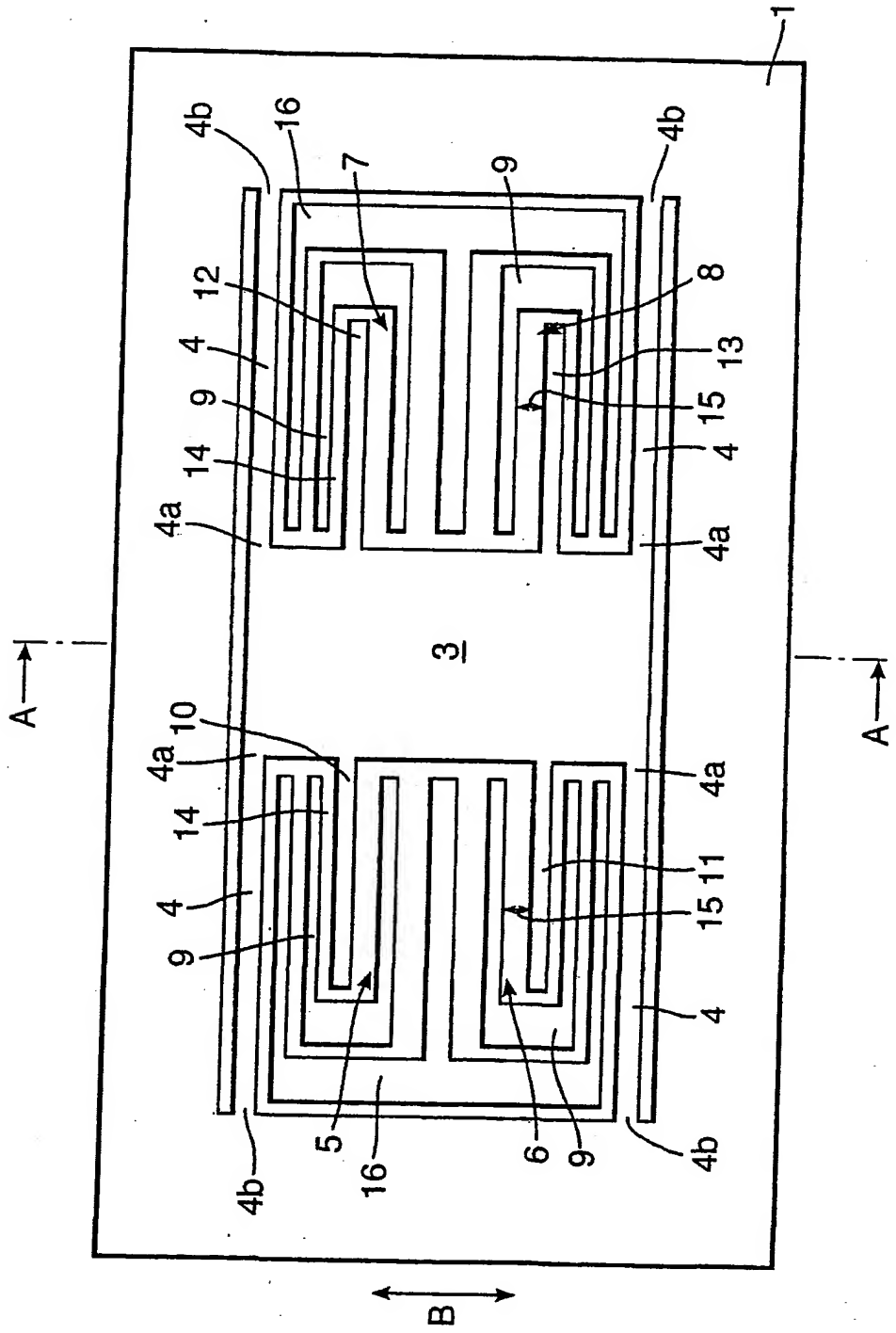
15. An accelerometer according to Claim 14, including at least four earth screens (16) located with the second inner open area, each being associated with and partially surrounding a respective one of the first (5), second (6), third (7) and fourth (8) arrays of fingers, being operable to shield the arrays (5, 6, 7, 8) of fingers from the inner support frame (18) and being electrically insulated from the inner support frame (18).

16. An accelerometer according to Claim 15, wherein the earth screens (16) are fixedly mounted by anodic bonding to the base (2).

17. An accelerometer according to Claim 16, wherein the means for providing the first and second drive voltages and for providing pulse width modulation thereto include a mark to space generator (22) for receiving a constant fixed reference voltage V_{ref} and for supplying complementary first and second drive voltages which together do not exceed V_{ref} to the first (5) and third (7) offset arrays of fingers and to the second (6) and fourth (8) offset arrays of fingers respectively, a pre-amp (23) for receiving an output voltage from the proof mass (3) corresponding to displacement thereof, a demodulator (24) for receiving and demodulating an output (25) from the pre-amp (23), an integrator/loop filter (26) for receiving, integrating and filtering an output (27) from the demodulator (24) and for in turn feeding a drive signal (28) to the mark to space generator (22) and a differential amplifier (29) with low pass filtering (30) for monitoring the first and second drive voltage values.

18. An accelerometer according to Claim 17, wherein the demodulator (24) includes monostable circuits for limiting the pulse width of reference signals from the demodulator (24).

Fig.1.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A
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B

Fig.3.

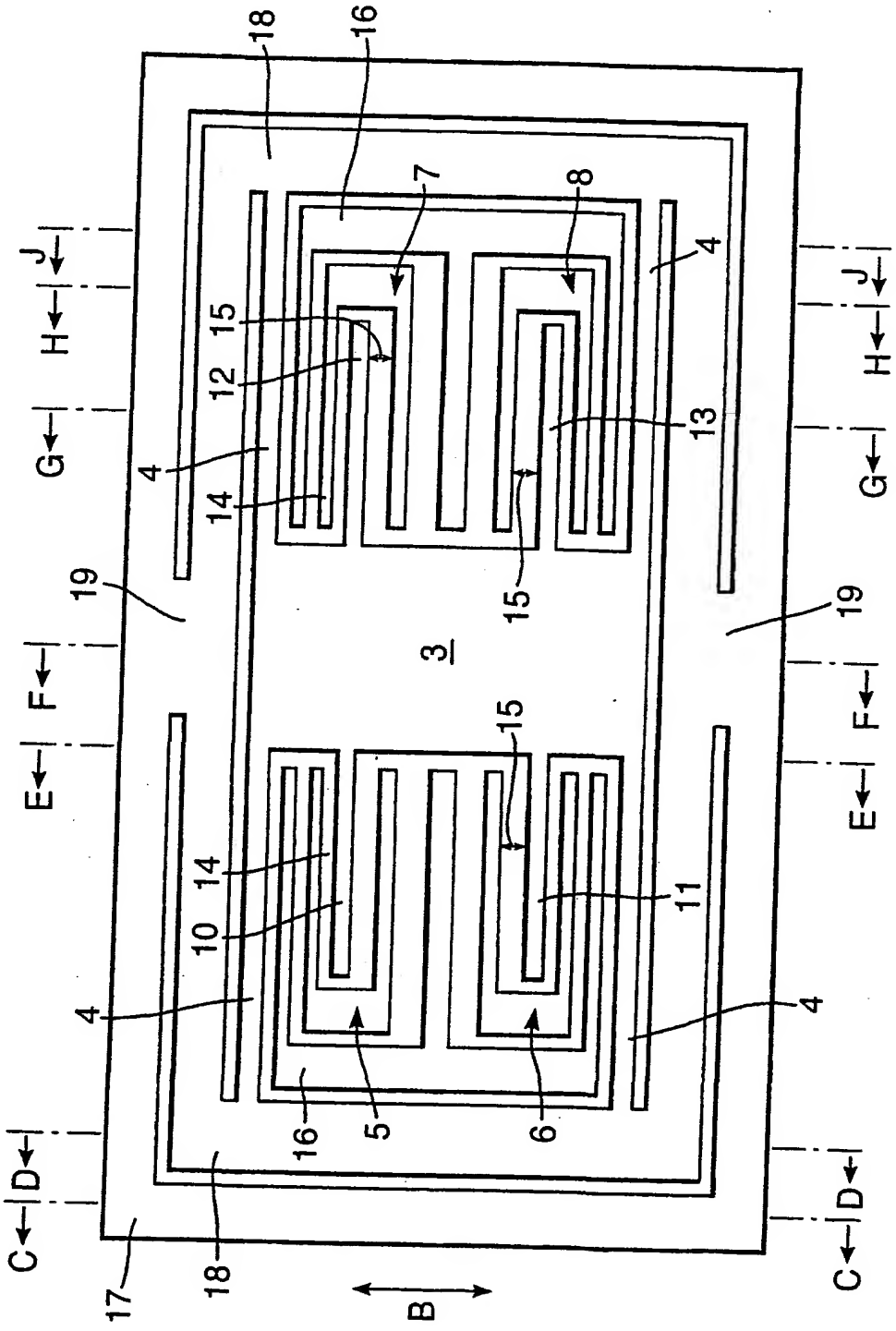

Fig.4.

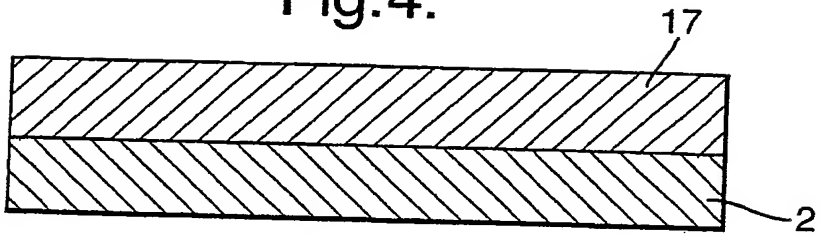

Fig.5.

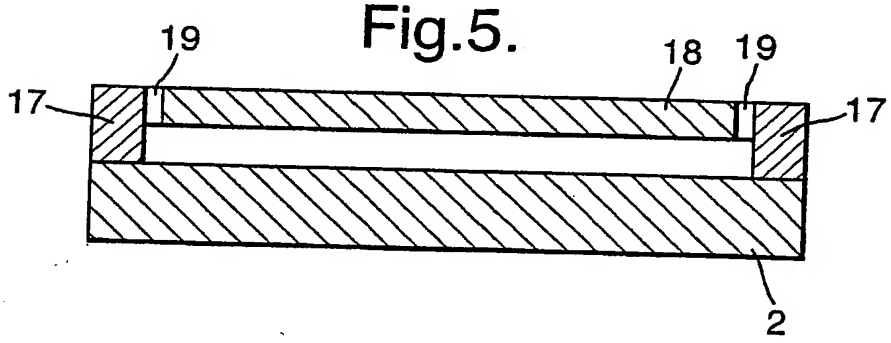

Fig.6.

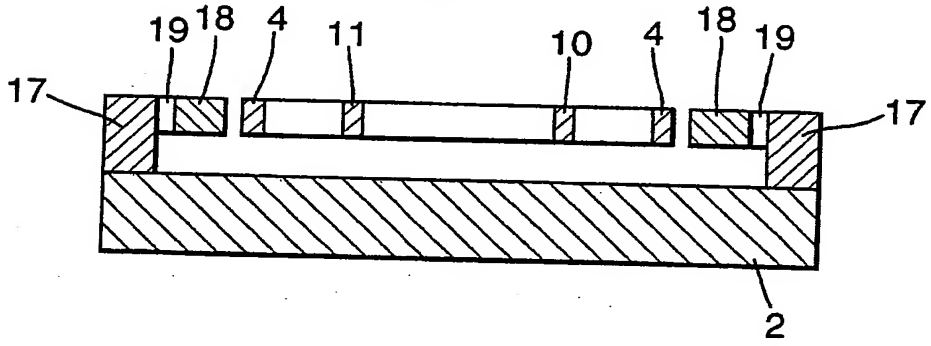

Fig.7.

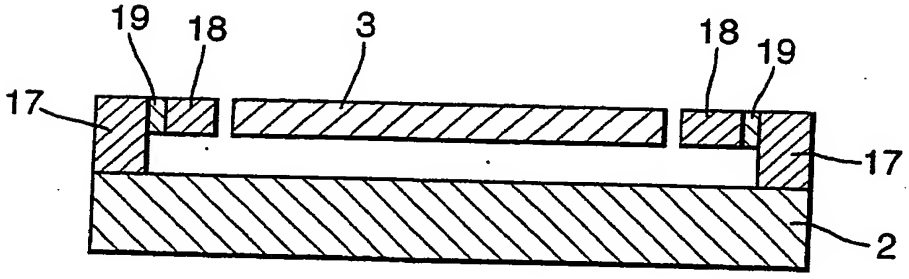

Fig.8.

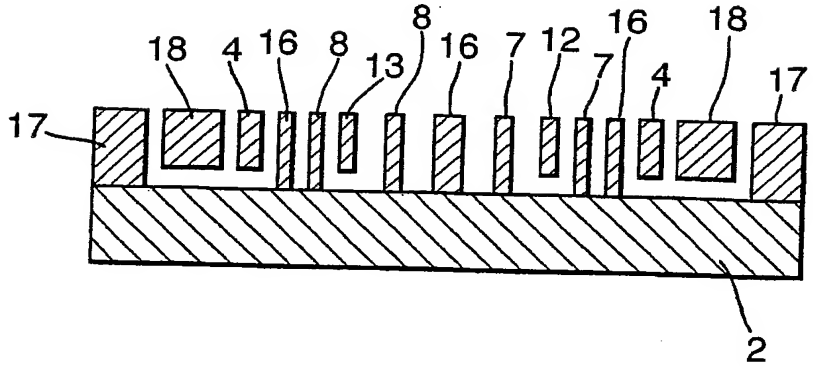

Fig.9.

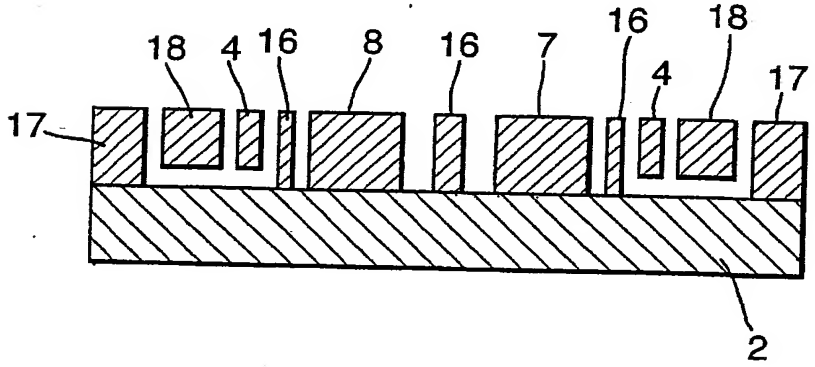

Fig.10.

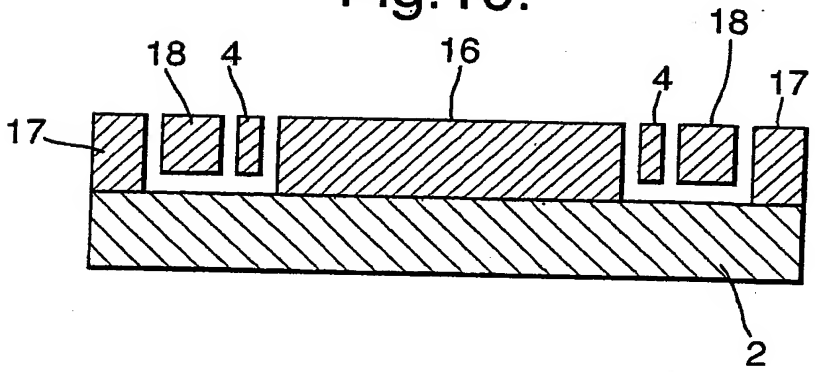

Fig.13.

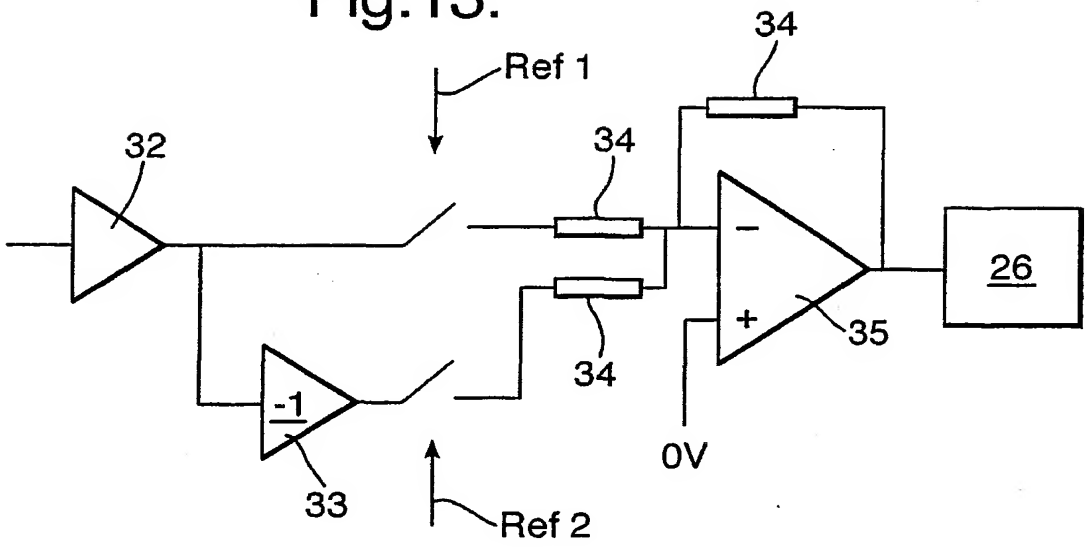

Fig.14.

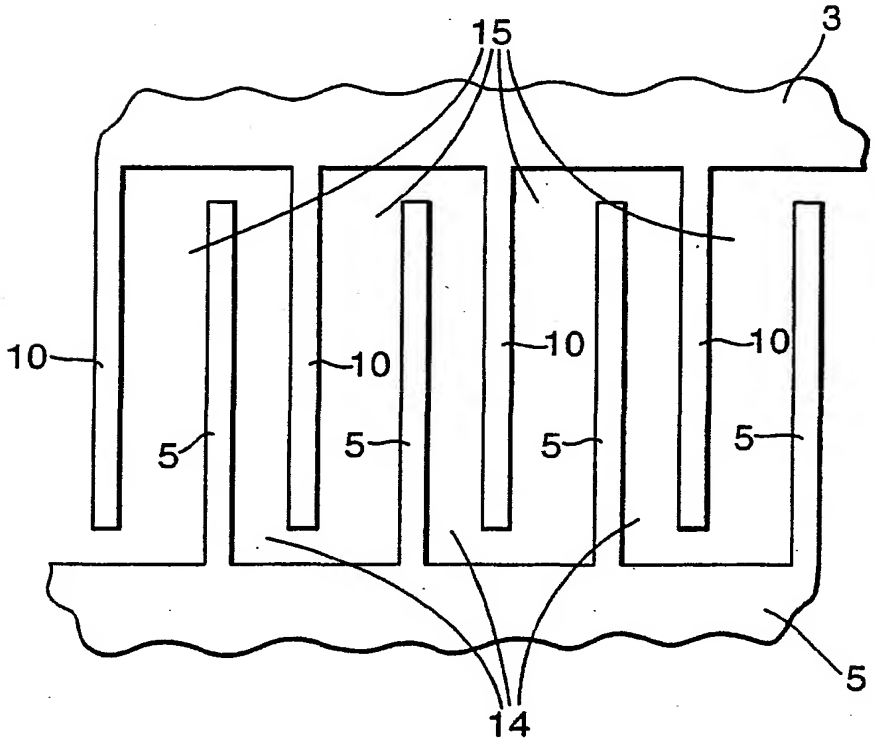

Fig.17.

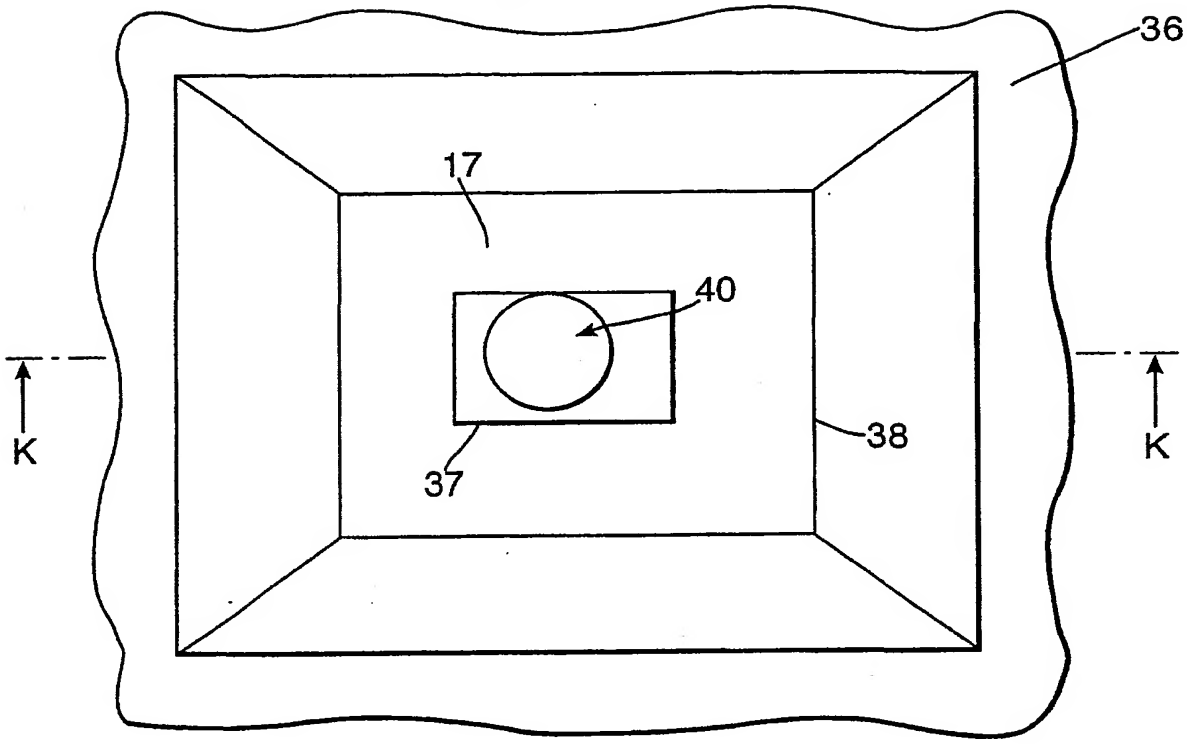

Fig.18.